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Life Cycle Cost Analysis – Integral Part of Road Network Management System

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Abstract

The article deals with economical aspect of Slovakia's Pavement Management System (PMS) – Road Network Management System (RNMS). Economic efficiency is a criterion, which enables us to create incisive outputs like strategy for allocation of limited funds between particular road sections, or the total funding amount necessary for preserving the road network in serviceable condition. In principle, economic efficiency assessment evaluates the impact of all Maintenance Repair & Rehabilitation (MR&R) actions. The positive effect – improvement of current state − of these actions has to overweight their construction costs. Economic efficiency can be evaluated by several methods, however, most commonly used is the Life-Cycle Cost Analysis (LCCA), which evaluates costs of various variants of MR&R actions.

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Keywords: Pavement Management System, Life-Cycle Cost Analysis, Road Network Administration, Cost Benefit Analysis, Maintenance Repair & Rehabilitation

1. Introduction

Within the scope of LCCA, impact of chosen MR&R action on particular pavement is evaluated, as each method has different costs and different impact on the improvement of technical parameters, such as increased serviceability or prolonged service life.

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Nomenclature

AD	Annual depreciation cost of vehicle, [€];
B	Pavement structure parameter
CBA	Cost-Benefit Analysis
CFF	Hourly cost of freight forwarders, [€/hour]
CTT	Circular Test Track
DW	Crew wages, [€]
HDM	Highway Design and Management
IRI	International Roughness Index
IRR	Internal Rate of Return
K_{ATG}	Annual transportation growth coefficient
K_{DEG}	Coefficient of function predicting condition of the pavement
LCCA	Life-Cycle Cost Analysis
MR&R	Maintenance Repair & Rehabilitation
n	Loading repetitions
N	Load repetition for pavement lifespan
NPV	Net Present Value
OC	Operational capacity
p(x)	Pavement deterioration parameter
PCH	Physical characteristics- horizontal and vertical alignment, category of the communication
PMS	Pavement Management System
PP	Payback Period
RNMS	Road Network Management System
RT	Road tax, [€]
RUB	Road user benefits
RUC	Road user costs, [€]
RUC_{DN}	Road user costs in “do nothing” variant
RUC_{DS}	Road user costs in “do something” variant
SAL	Standard axle load
T	Years 1 – Y
TCH	Traffic characteristic- intensity and composition of traffic
TTC	Travel time costs, [€]
VEL	Economic life of vehicle
VFCH	Vehicle fleet characteristic- category of vehicles and their technical level
VI	Vehicle insurance costs, [€]
VOC	Vehicle operating costs, [€]
Y	Service life of MR&R action

Furthermore, impact on road user costs and social & environmental costs is evaluated. The economic efficiency analysis is carried out with the use of Cost-Benefit Analysis. CBA evaluates positive impacts – benefits – related to improved operational parameters of the pavement in comparison to costs for applied MR&R actions. The Payback Period, Internal Rate of Return and Net Present Value are economic indicators of CBA.

This article gives an overview of most crucial part of LCCA – estimation of benefits, and describes the objective of CBA and its position within RNMS processes.

2. Illustrations

Identification and calculation of benefits generated through repaired pavements is a key factor for economic efficiency calculation. Benefits are calculated as a difference in transportation costs before the MR&R action and decreased transportation costs stemming from improved pavement parameters as a result of the MR&R action. Benefits may be internal or external. Internal benefits are the road user costs, which consist of vehicle operating costs and travel time costs. External benefits are savings from emission, noise and accident rate reduction.

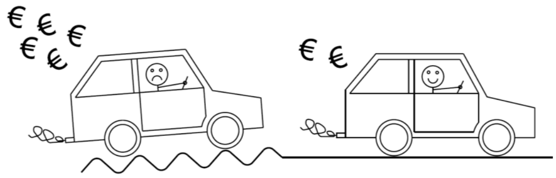

Fig. 1. Hyperbolization of road user costs dependency from pavement condition.

Dust particular matter and vibration are not crucial, but they monetization adds to the overall benefits. At this point they are not included in the RNMS. The vehicle operating costs are the transportation costs, which include fuel consumption, lubricant consumption, car maintenance, wearing of tires, and transportation time of cargo and passengers. Vehicle operating costs are a function of following factors:

$$UC = VOC + TTC = F\left(TCH, OC, PCH, VFCH\right) \tag{1}$$

In the road user cost calculation, HDM coefficients are employed [1]. Those coefficients are based on horizontal and vertical alignment of the road. Among all surface characteristics of the pavement, the most important is the longitudinal roughness expressed through International Roughness Index. The calculation of user cost is defined for the consumption of fuel, lubricants, travel time, tire wear, spare parts and vehicle maintenance.

Time savings are the result of increased speed on repaired road section, and they can be monetized. The changes in travel time are adjusted by Highway Development and Management coefficients. For the monetization of time savings, it is important to know, whether we deal with the time of passengers or cargo transportation time. Currently, in the calculations, we are considering only cargo transportation times.

One-hour costs of freight forwarders are used to calculate total cost of total cargo transportation time. The hourly cost of freight forwarders is calculated according to equation (2).

$$CFF = \frac{AD + DW + RT + VI}{VEL} \tag{2}$$

Road user benefits are calculated as savings, i.e. difference between higher road user costs prior to the MR&R action and road user costs after the MR&R action. Each MR&R method has its expected serviceability, defined by its pavement performance functions – equation (3).

$$RUB = \sum_{T=1}^{Z}\left[\left(RUC_{DS} - RUC_{DN}\right)\cdot K_{DEG} \cdot K_{ATG}\right]_T \tag{3}$$

$$K_{DEG} = 1 - \left(\frac{T}{Y}\right) \tag{4}$$

The coefficient of degradation K_{DEG}, equation (4), is a mathematical expression for degradation of surface characteristics. This coefficient is a parameter of a fundamental importance for the accuracy and validity of economic efficiency calculation.

For the needs of the RNMS, the trend lines for degradation of skid resistance, longitudinal and transverse roughness and surface distress were derived according to outputs of Circular Test Track, which is an outdoor accelerated pavement testing facility [2] [3]. At this facility, several pavement designs were tested and trend lines for degradation were derived for various traffic intensities. All tests performed on this facility were carried out in 1:1 scale – real life traffic load was applied on real life pavements – this way, accuracy of the results was ensured and these results could be used to derive exact equations. The equations arise as result of first performed measurements [4] and, at present, they are being refined on the base of cyclical measurement performed by the department of road databank. These equations, since they were deterministic in their nature, were derived on the basis of regression analysis. As an example, we present the trend line for degradation of longitudinal roughness for specific pavement type in Figure 2. In this Figure, *n* is the number of SAL repetitions from the start of service to the expected date of pavement repair; *N* is the total number of SAL repetitions needed to achieve the load limit value. In this case, the parameter B 2.0 was derived for flexible pavements and parameter B 3.0 was derived for semi-rigid pavements. A warning value is at 60% difference between initial and limit value. Critical value is 40%.

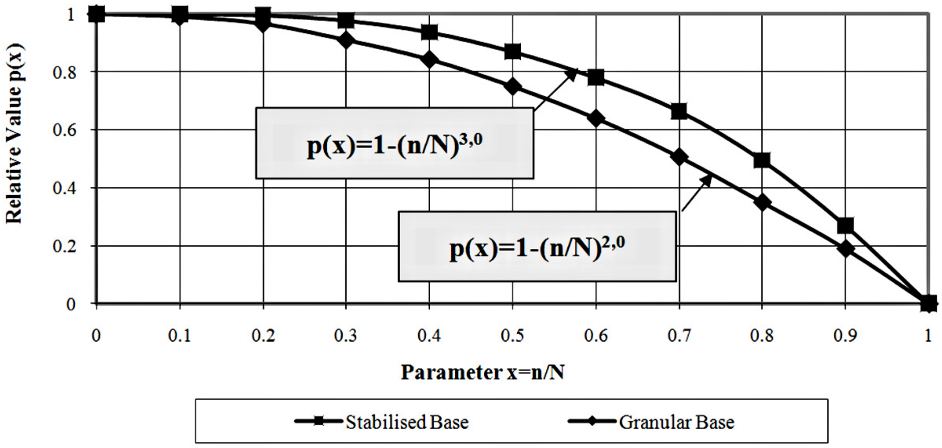

Fig. 2. Degradation functions of IRI for flexible pavements. [5]

Currently, the CTT is not in service anymore, mainly due to energy costs of its operation. At present, the trend lines of degradation are being verified using results of measurements carried out for the needs of Slovak Road Database [6]. However, given the large number of input variables and conditions, and thus the large dispersion of the results, construction of a new experimental test facility started at University of Zilina. This facility will simulate traffic load, and subsequently, scrutinize inducted pavement response on a 1:1 model. This research will allow us to analyze all the physical-mechanical properties of the pavement under given conditions. Subsequently, it will be possible, at the level of absolute model, to analyze all the parameters by specifying their existing trend lines of degradation.

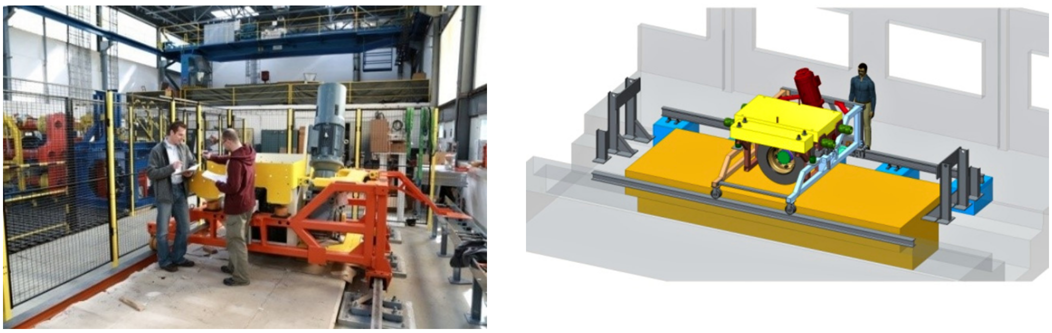

Fig. 3. Accelerated pavement-testing facility of University of Žilina.

Apart from trend lines for degradation of skid resistance, longitudinal and transverse roughness and surface distress, bearing capacity is also a significant factor influencing the overall results [7], however, the calculations performed in the Comprehensive Analysis of the Pavement Bearing Capacity software are out of scope of this article.

3. Cost benefit analysis

Cost-benefit analysis is a formal analysis of the impacts of a measure or programme, designed to assess whether the advantages (benefits) of the measure or programme are greater than its disadvantages (costs).

The calculation of economic efficiency of selected repairs is based on comparison of the benefits they will produce and their construction and maintenance costs. In view of the fact that it is necessary to incorporate a huge amount of data from the pavement evaluation, future maintenance costs, year in which the repair will take place, expected service life of the repair and calculated benefits, an algorithm of this procedure was created. Diagram of the algorithm is shown in Figure 4. The construction costs for particular MR&R method are included in the library of technologies, which is annually actualized with new market prices, paid by the administrator.

For project level, the CBA output shows if and how effective the repair action is. Economic indicators have threshold at which the project can be called „effective“. IRR has to be higher than discount rate; net present value has to be higher than zero, Benefit-Cost Ratio has to be higher than 1.0 and payback period has to fall within the lifespan of repaired pavement.

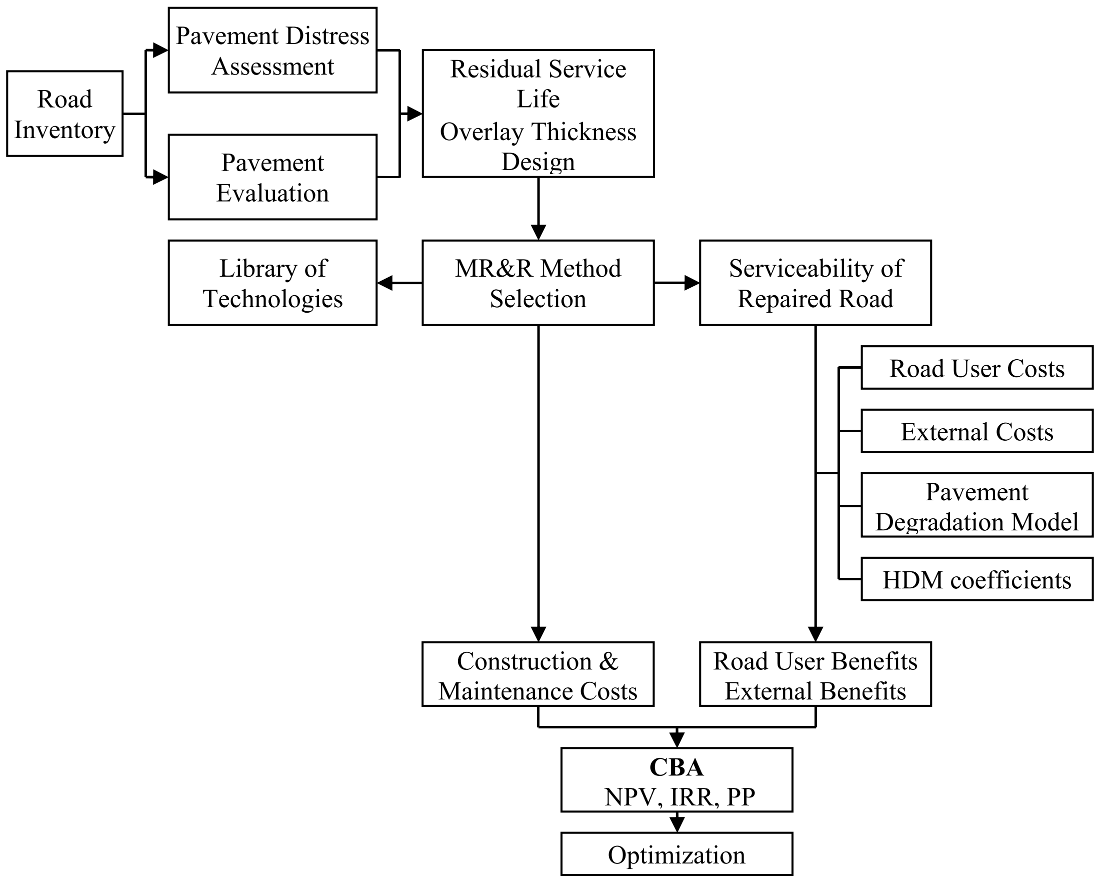

Fig. 4. CBA algorithm within RNMS.

For road network level, the final output of the whole CBA is used in a cumulative table, which includes a final list of selected road sections and corresponding repair types. The table shows all necessary data required for final decision, In particular pavement operating condition index, appropriate repair action, traffic load, and, as a CBA output – repair procurement costs and internal rate of return. Price for the repair is only an estimated value; the real value will be based on competition process where contractor for the construction works will be selected.

4. Conclusion

The application of LCCA and CBA provides us with fund allocation strategies and creation of site specific plans for MR&R actions, i.e. plans for meeting the performance objective. The application proved that the resources are allocated to road sections which have the highest demand for repairs, thus financial funds are used effectively. The saved funds are in turn used as additional resources for further repairs. Another important fact is that this systematic approach increased the discipline of subcontractors of repair works, employed by road administrators. The road network administrator has, by means of LCCA, a huge number of results, enabling him to optimize his activities; for example, the trend lines of roughness, skid resistance or surface damage.

RNMS provides a full set of outputs for network and project level assessment. In particular, the prioritization of fund expenditures allocated for MR&R policies and creation of site specific plans for MR&R actions, i.e. plans for meeting the performance objective. In addition, several others outputs are generated, for instance pavement distress data and traffic related data, data regarding the results of the evaluation – pavement operating condition index, IRI, selected MR&R technology, their costs, traffic load and internal rate of return.

Acknowledgements

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